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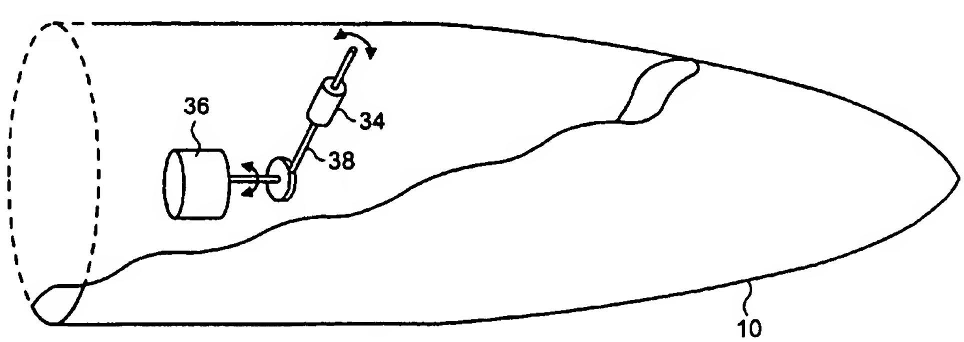
(54) Title: GUIDED PROJECTILE



(57) Abstract: A projectile guidance system includes a spin-stabilised projectile (10) having a variable internal mass distribution (34, 36, 38) controlled by actuators. As a result the trajectory of the projectile can be varied during flight by varying the mass distribution and hence the centre of gravity (12) or rate of spin.

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GUIDED PROJECTILE

The invention relates to a guided projectile, for example a spin stabilised projectile such as an artillery shell.

The dynamics of a spinning projectile are generally well known and are summarised in, for example, "The Aerodynamics of a Spinning Shell", Fowler, Philosophical Transactions of the Royal Society (London) (A) Volume 221, pages 295 to 387. These dynamics will be well known to the skilled person and are not therefore described in great detail here. However, for ease of reference, the basic principles are set out below.

The various principal forces acting on a projectile designated generally 10 as shown in Fig. 1. The forces can effectively be divided into mass forces acting effectively on the centre of gravity 12 of the projectile and aerodynamic forces including "lift" and "cross-wind" force acting at the centre of pressure 14 of the wind force which is usually forward of the centre of gravity (although this is dependent on flow conditions).

The principal mass force is the gravitational force which acts on the centre of gravity 12 downwardly as shown by arrow A giving rise to the familiar parabolic motion of the projectile 10 in flight. For the case of a non-spinning projectile, the principal aerodynamic forces are drag which is simply the velocity retarding component of air resistance and the cross-wind force.

The cross-wind force arises because of the yaw of the projectile. Referring again to Fig. 1 it can be seen that the longitudinal axis B of the projectile is at an angle α to the direction in which the centre of gravity 12 is travelling which is denoted by arrow V (velocity). As a result a component of the drag exerts a force denoted by arrow C at the centre of pressure 14 which is horizontal and perpendicular to the direction of motion V of the projectile. As

the centre of pressure 14 is forward of the centre of gravity, this gives rise to a moment tending to increase the yaw angle α. The initial yaw is imparted as the projectile leaves a firing barrel resulting from turbulent effects and is currently unavoidable in existing systems.

The projectile 10 is stabilised by spin about its longitudinal axis B. This spin is imparted by rifling in the firing barrel, that is a spiral groove of predetermined pitch cut into the barrel. In the embodiment shown the spin is denoted by arrow D in a clockwise direction viewed from behind. Because of the spin, a further aerodynamic force is introduced, the "Magnus force". As is well known, the spin of the projectile couples with the cross-wind component of drag as discussed above such that the air velocity transverse to the projectile direction above and below the projectile are asymmetric. As a result the air velocity is higher and hence the pressure lower below the projectile. This gives rise to a downward force on the projectile denoted by arrow E which applies at a centre of pressure of the Magnus force 16 generally located behind the centre of gravity 12. The resulting moment about the centre of gravity 12 urges the bullet to pivot upwardly.

However the spin D of the projectile introduces a further gyroscopic effect. Following the well known precessing effect, the direction of precession is perpendicular to both the moment imparted by the Magnus force E and the axis of spin B and, in the case of the direction of spin D shown, tends to act in a direction to decrease the yaw angle α as shown by direction arrow F. In addition, because of the interaction of the spin of the projectile 10 with the moment caused by the cross-wind force C, a perpendicular moment is imparted on the projectile urging the tip to pivot upwardly relative to the centre of gravity. It will be appreciated that these various forces and moments interact and vary continuously as the longitudinal axis of the projectile varies its

direction. The Magnus force effect however provides an overriding stabilising factor, and the departure of the projectile from its theoretical trajectory is termed "drift".

These various effects are well known and the resulting behaviour of a projectile has been studied closely both empirically and theoretically. In practice, however, it is necessary to use complex tables, algorithms or computer programs to predict the exact trajectory of a projectile and even then additional forces such as cross-winds (which are not taken into effect in the force diagram of Fig. 1 and should not be confused with the cross-wind component of drag) are also important factors. Accordingly a system is required for guiding projectiles.

Various known systems have been proposed. Generally these comprise systems where the surface geometry of the projectile is varied during flight, for example by angling fins and so forth, or where additional thrusters are provided on the projectile and fired as appropriate to adjust its direction of flight.

For example in US 4,013,245, in an optically guided projectile, a steering vane extends from the body of the projectile in response to detected deviation from the target. In US 4,193,567 a projectile includes a sidewardly directed jet duct providing a sidewards guide force. US 4,566,656 discloses a projectile including a rod extending from the rear of the projectile which is reflected to alter the trajectory of the projectile dependent on received driving signals.

However known systems, in particular those including projecting parts, can be unsuitable for shells fired from barrels which preferably have general surface integrity and a profile adapted to be fired from a cylindrical barrel.

The invention is set out in the appended claims. The invention provides a system in which the shell is guided dependent on internal actuation such that the surface integrity of the projectile need not be altered in any way, simplifying

production and loading, and improving efficiency and accuracy. In particular, variation of the mass distribution within the projectile varies the position of the centre of gravity as a result of which the interaction between the centre of gravity and the centres of pressure can be controlled so as to control the trajectory of the projectile.

An embodiment of the invention will be described, by way of example, with reference to the drawings of which:

Fig. 1 shows the basic dynamics of a spin stabilised projectile;

Fig. 2 shows a guided projectile trajectory according to the present invention;

Fig. 3a is a cut-away view of a projectile having an internally movable mass;

Fig. 3b is a cut-away view of a projectile having an internally movable spinning mass;

Fig. 4 is a block diagram of a guidance system housed within the projectile; and

Fig. 5 is a perspective view of a projectile having an adjustable drag member.

Referring to Fig. 2 a general overview of the system can be seen. The projectile 10 is shown in various positions in flight between a firing barrel 20 and a target 24. A GPS (Global Positioning System) satellite or other positioning system controller 26 is in duplex communication with the projectile 10 during its trajectory and feeds re-positioning information to the projectile to correct its trajectory based on the instantaneous position of the projectile and, for example, a comparison with its desired trajectory to arrive at the target 24. The re-positioning information can be provided continuously, intermittently, or

in a single correction at one point in the projectile trajectory. As a result a closed loop system is provided such that continual correction of the projectile trajectory is achieved taking into account, for example, differing cross-winds G_1, G_2, G_3 at different altitudes or positions on the trajectory.

Physical correction of the trajectory is shown with reference to Fig. 3a. The projectile 10 includes a mass 30 reciprocably mounted on a track 32. Movement of the mass along the track will alter the position of the centre of gravity 12 of the shell. Control of the movement is carried out by a motor mounted, for example, within the mass (and comprising a component of the mass) under control of a controller (not shown) in duplex communication with the external guidance system 26.

Reverting back to Fig. 1 it will be recalled that the various forces on the spinning projectile 10 are governed principally by various moments relative to the centre of gravity 12 and in particular the cross-wind force C and Magnus force E together with their interaction with the spin D of the projectile 10. As a result movement of the centre of the gravity forwardly or rearwardly will affect, inter alia, the yaw of the projectile which in turn will give rise to controllable corrections in the trajectory.

For example moving the centre of gravity rearwardly towards the centre of pressure of the Magnus force 16 will decrease the moment in the perpendicular plane and hence decrease the restoring force F against the direction of yaw α. Movement of the centre of gravity forwardly will have the opposite effect.

Similarly, movement of the centre of gravity forwardly towards the centre of pressure 14 of the cross-wind force will decrease the moment in the horizontal plane and hence the moment in the upwards direction and hence drift upwards, and movement away from the centre of pressure of cross-wind force

will have the converse effect.

It will be noted that the Magnus force and cross-wind forces have proportional magnitudes governed inter alia by the velocity of the projectile and the rate of spin, such that their proportion or magnitudes can be governed to allow a desired force ratio.

Referring to Fig. 3b an alternative manner of trajectory control is shown. In this instance a spinning mass 34 is mounted within the projectile 10 driven by, for example, a motor 36. The motor 36 is fixed relative to the casing and can be driven in either direction to rotate the weight 34. As a result the rotational speed of the projectile 10 can be increased or retarded as desired. The weight 34 can in addition be movable in a radial direction along a shaft 38 allowing confined control of the amount of spin increase or retard. In alternative embodiments (not shown) the spin can be varied by effectively altering the moment of inertia of the projectile 10 by moving one or more masses radially inwardly (to increase the spin) or outwardly (to decrease the spin) again under the control of actuators. In a variant on this, a "one way" system could be introduced in which a mass is mounted close to the axis of spin of the projectile and slidable radially. If it is desired to retard the system a clutch is released on the mass allowing it to slide outwards on the centrifugal force alone. This removes the requirement for additional actuator but reduces the amount of spin control available. In yet a further alternative, a floating mass is provided on bearings relative to the projectile casing. As a result when spin is enparted to the projectile through the rifling of the firing barrel, the mass remains rotationally at rest on nearly at rest. A clutch mechanism can be employed to engage the mass with the casing to retard the spin.

Control of the projectile under the scheme shown in Fig. 3b would be equivalent to that in the arrangement shown in Fig. 3a. The spin is simply

another parameter which can be varied to control the trajectory of the projectile as it affects both the Magnus force and the gyroscopic effects. Accordingly instantaneous control of the spin speed will allow correction of the trajectory and this can be based on instantaneous calculations or look-up tables or any other appropriate mechanism. It will be appreciated that the projectile may incorporate both spin-affecting and centre of gravity-affecting mechanisms allowing an additional fine level of control by manipulation of both parameters with the corresponding combined effect.

Referring now to Fig. 4, the basic blocks of the projectile guidance system 40 within the projectile are shown. Central to the system is the guidance control module 42 which communicates with a communication input/output module 44 which in turn communicates with an external guidance system. Based on an indication of the current position of the projectile and/or additional guidance information received from the external guidance system, the guidance control module sends control instructions to an actuator control module 46 which in turn varies the mass distribution within the projectile so as to alter the centre of gravity as discussed above.

It will be noted that this control can be carried out in various manners. In the system shown, the trajectory of the shell/target location is programmed into the projectile 10 and maintained at the guidance control module 42. Current position data is gathered using a GPS satellite 26 which communicates with communication module 44. The mass distribution of the projectile is then updated throughout the flight so as to match the projectile trajectory with the desired trajectory programmed at the guidance control module.

The amount of adjustment required to correct the trajectory of the projectile can be calculated instantaneously dependent on instantaneous parameters of the projectile such as spin and velocity which can be measured

instantaneously by the guidance control module in conjunction with the GPS system as appropriate. Alternatively, a desired adjustment value can be correlated with a predetermined centre of gravity from a look-up table and the mass distribution varied accordingly. Alternatively, or in addition, the closed loop system including the GPS feedback can be used for instantaneous correction such that deviations from the desired trajectory are instantaneously corrected, and over correction automatically compensated upon detection from the GPS feedback.

As an alternative to continuous control and adjustment of the trajectory, the system can allow intermittent adjustment, for example at predetermined time intervals during the trajectory. Alternatively still, in a simpler version, a single control "burst" can be carried out at one point during the trajectory. For example after the projectile has left the firing barrel, its position can be assessed and any deviations from the desired trajectory (or any other adjustment of the trajectory) achieved by calculating a single correct position for the centre of gravity of the projectile. It will be appreciated that the earlier this correction is made, the greater adjustment will result over the course of the whole trajectory, as the adjustment is effectively integrated over time. However it is equally possible to carry out a single correction later in the trajectory which allows greater accuracy but a smaller adjustment range.

The target position can be programmed either prior to launch, at launch or during flight. As a result the burden on the guidance control module 42 may be lessened in favour of an external guidance control which simply sends adjustment commands to the shell to vary the trajectory. The range of variation of trajectory of the system is limited by the range of motion of the centre of gravity and the resultant forces that movement gives rise to, and in particular any instability in the projectile that may be introduced by over-adjustment of

the centre of gravity. However within those limits, combined with the time of flight of the projectile, in addition to target data being entered during flight, a moving target may be tracked by the system.

The method of interfacing with the shell guidance system may be through a direct connection to the shell or via indirect methods such as radio, inductive or capacitative coupling. In addition it will be seen that the system does not necessarily rely on a GPS system. Alternatively the shell could be laser guided or include radar detection capability for identifying the position of the target instantaneously, calculating the desired trajectory and adjusting accordingly, extrapolating data from successive positional readings relative to the target.

It will be appreciated that the moving mass system shown in Fig. 3 is one crude manner of achieving mass distribution variation and hence varying the centre of gravity. The mass may be moved by rotary to linear actuation, linear motors, cable systems and so forth using electric, pneumatic or hydraulic power sources. The mass itself is of course an additional load on the shell but can include much of the drive system, power and control systems such that as much of the excess mass as possible is taken up by the guidance system itself. In addition although a single mass is shown moving in a single dimension, the variation of mass distribution can of course be considerably more complex and can involve multiple masses or a fluid mass moving independently in multiple dimensions.

It will be noted in the discussion above that the principal trajectory parameter that can be adjusted is the lateral displacement – the range will to a large extent be unaffected although variations in the inclination of the projectile may be used to a limited extent to vary the profile of the trajectory parabola which will have some effect on the range. In a preferred embodiment shown in

Fig. 5, the projectile includes a further drag member 50. In the arrangement shown the drag member 50 has a similar profile to that of the projectile but is pivotable into and out of the air stream to increase or decrease the drag. As a result the range of the projectile can be decreased, although not increased, giving rise to yet further trajectory control. Adjustments of the drag member can be made at the same time as adjustment of the centre of mass, the interrelated effects being calculated instantaneously or derived from appropriate look-up tables. The means of operation of the drag member are not shown here but will be familiar to the skilled person. For example a hydraulic linear actuator can be used to alter the angle at which the drag member projects using a simple linkage. It will be appreciated that although this additional member affects the surface integrity of the projectile 10 to a certain extent, the overall trajectory control is nonetheless achieved with a greatly reduced effect on the surface integrity of the projectile compared to known systems.

The types of actuator, control system, control algorithm or instruction set used will be familiar to the skilled person and are not explored in detail here. The level of calculation can take into account factors such as three dimensional variation of the centre of gravity, interaction of the centre of gravity with the Magnus and cross-wind force centres of pressure, variation of the centres of pressure themselves as the parameters of the projectile as a whole vary with the moving centre of gravity, interaction of instantaneous drag, spin and velocity values and so forth. These calculations can be carried out either instantaneously or can form the basis of look-up tables accessed by the control module during flight. A simplified system may be achieved using closed loop feed-back such that instantaneous auto-correction is achieved as the flight of the projectile varies. As a result the system provides an improvement over conventional methods of guiding projectiles involved using fins or jets to change the

trajectory of the projectile. With projectiles fired from barrels, the use of fins is severely restricted in any event and in the present case can be removed altogether. As a result a projectile is guided without any external mechanism thus providing no restriction on it being fired from a barrel.

CLAIMS

1. A spin stabilised guided projectile comprising a projectile body, a distributable mass within the body, and a controller arranged to vary the mass distribution to adjust the projectile trajectory.

2. A projectile as claimed in claim 1 in which the mass distribution is varied to adjust the centre of gravity of the projectile.

3. A projectile as claimed in claim 1 or claim 2 in which the mass distribution is varied to adjust the rate of spin of the projectile.

4. A projectile as claimed in any preceding claim in which the distributable mass includes a mass and an actuator controlled by the controller to move the mass.

5. A projectile as claimed in claim 4 in which the actuator is one of a rotary to linear actuator, a linear actuator or a cable system.

6. A projectile as claimed in claim 4 or 5 in which the actuator uses one of electric, pneumatic or hydraulic power sources.

7. A projectile as claimed in any preceding claim further including a drag member adjustable to vary the projectile drag.

8. A projectile as claimed in any preceding claim in which the controller

adjusts the projectile trajectory based on GPS data.

9. A projectile guidance system for a spin stabilised projectile including a projectile having a variable mass distribution and an external guidance data transmitter, in which the external guidance data transmitter transmits guidance data to the projectile, and the mass distribution of the projectile varies based on the data received.

10. A system as claimed in claim 9 in which the mass distribution of the projectile is varied continuously.

11. A system as claimed in claim 9 in which the mass distribution of the projectile is varied intermittently.

12. A system as claimed in claim 9 in which the mass distribution of the projectile is varied in a single correction.

13. A system as claimed in any of claims 9 to 12 in which the projectile is as claimed in any of claims 1 to 8.

14. A mass distribution apparatus for a spin stabilised guided projectile comprising an actuator and a mass movable by the actuator.

15. An apparatus as claimed in claim 14 in which the actuator is one of a rotary to linear actuator, a linear motor or a cable system.

16. An apparatus as claimed in claim 14 or 15 in which the actuator uses an

electric, pneumatic or hydraulic power source.

17. An apparatus as claimed in any of claims 14 to 16 further including a controller arranged to control the actuator to vary the mass distribution.

18. A projectile having a longitudinal axis and an apparatus as claimed in any of claims 14 to 17 in which the actuator is arranged to move the mass in a direction having a radial component relative to the axis and/or as axial component.

19. A method of guiding a spin stabilised projectile including obtaining instantaneous trajectory data and varying the mass distribution of the projectile to adjust the trajectory based on the data.

20. A projectile system and method as claimed in any preceding claim substantially as herein described and as illustrated by figures 2 to 5.

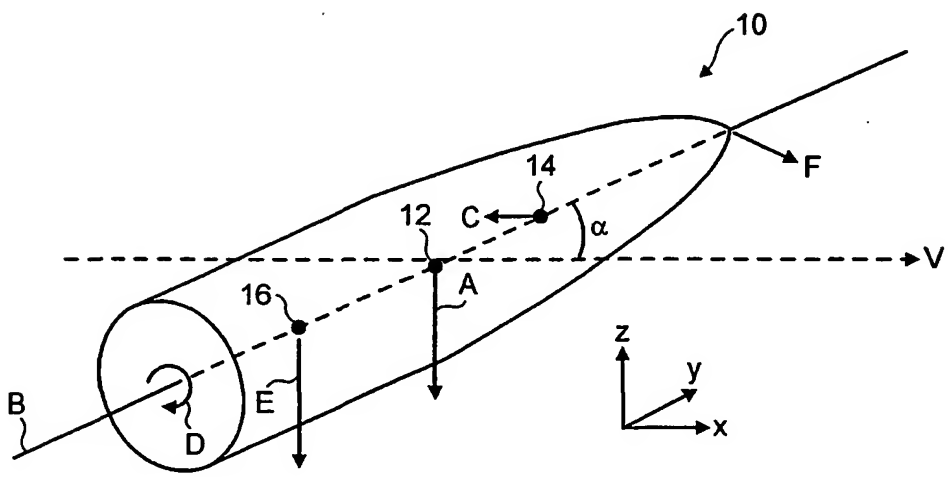

FIG. 1

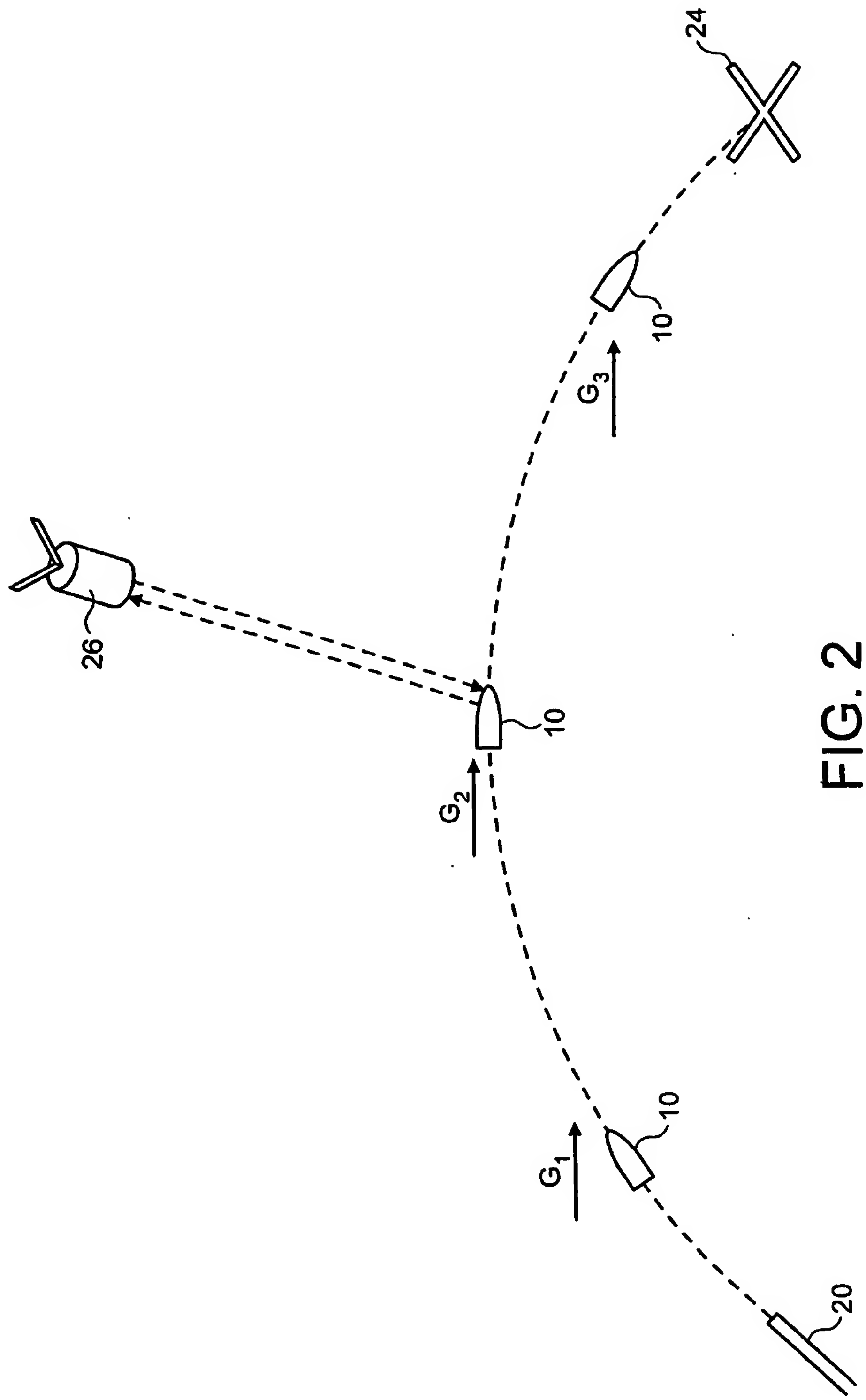

FIG. 2

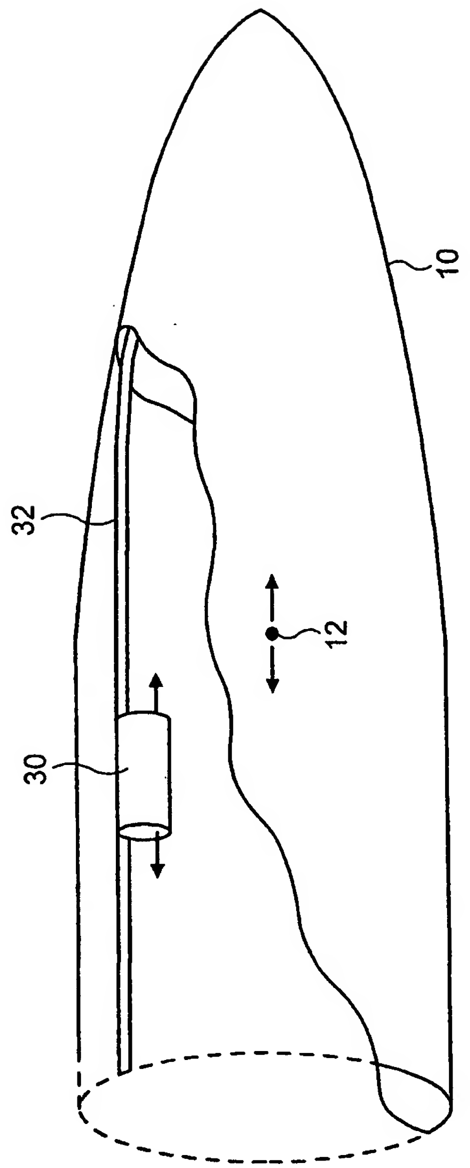

FIG. 3A

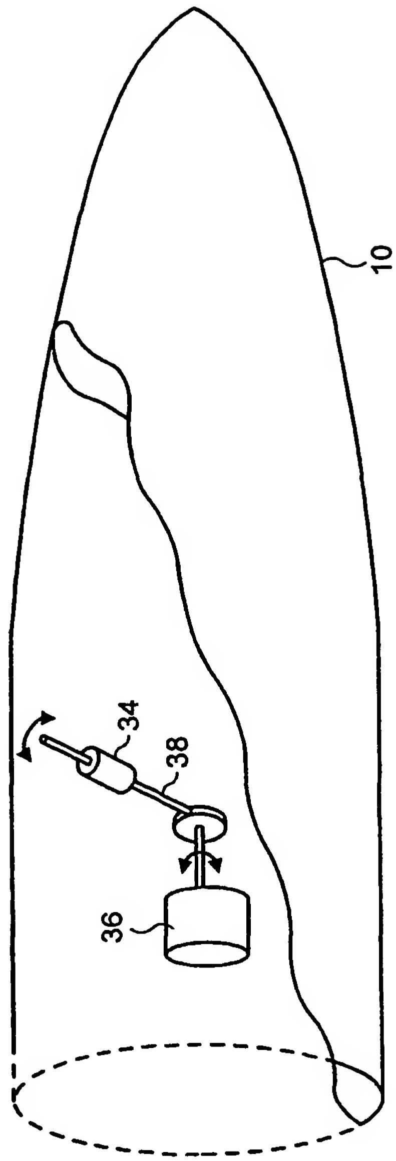

FIG. 3B

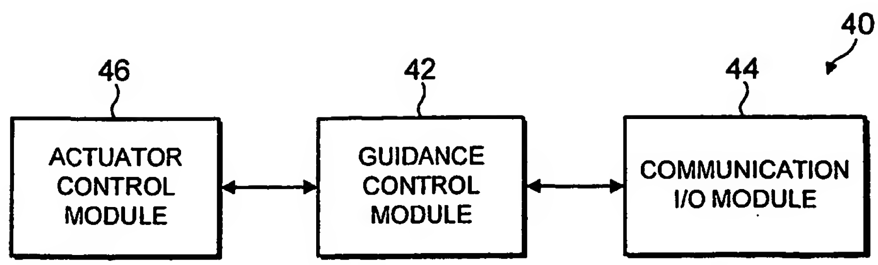
40
46
42
44
ACTUATOR CONTROL MODULE
GUIDANCE CONTROL MODULE
COMMUNICATION I/O MODULE

FIG. 4

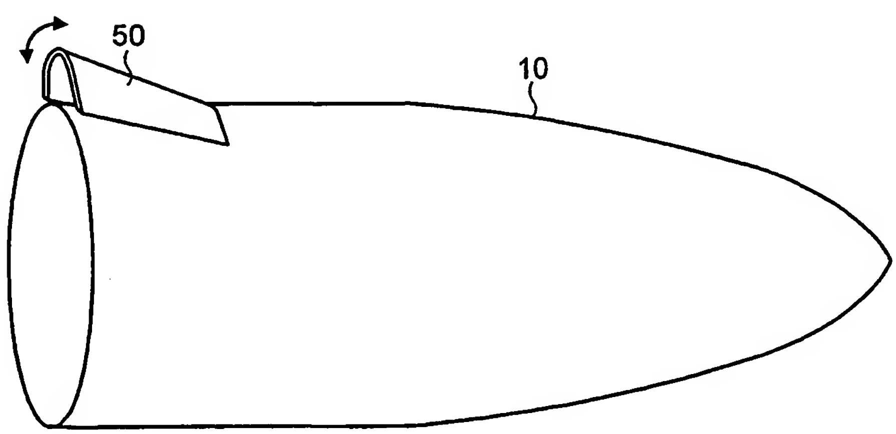
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FIG. 5

INTERNATIONAL SEARCH REPORT

Int[ernati]onal Application No
PCT/GB 01/03478

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F42B10/60 F42B10/54 F42B10/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F42B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y		7
Y	DE 198 24 288 A (RHEINMETALL W & M GMBH) 2 December 1999 (1999-12-02) * abstract *	7
X	US 2 774 305 A (FITZGERALD THOMAS W ET AL) 18 December 1956 (1956-12-18) the whole document	1-6,8-20
X	US 4 784 350 A (DARDEN RALPH M) 15 November 1988 (1988-11-15) the whole document	1-3,19

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
19 September 2001	28/09/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Van der Plas, J

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

International Application No
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